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Groundwater - Surface Water Integration Study in the Grand Prairie of Arkansas

Carl L. Griffis
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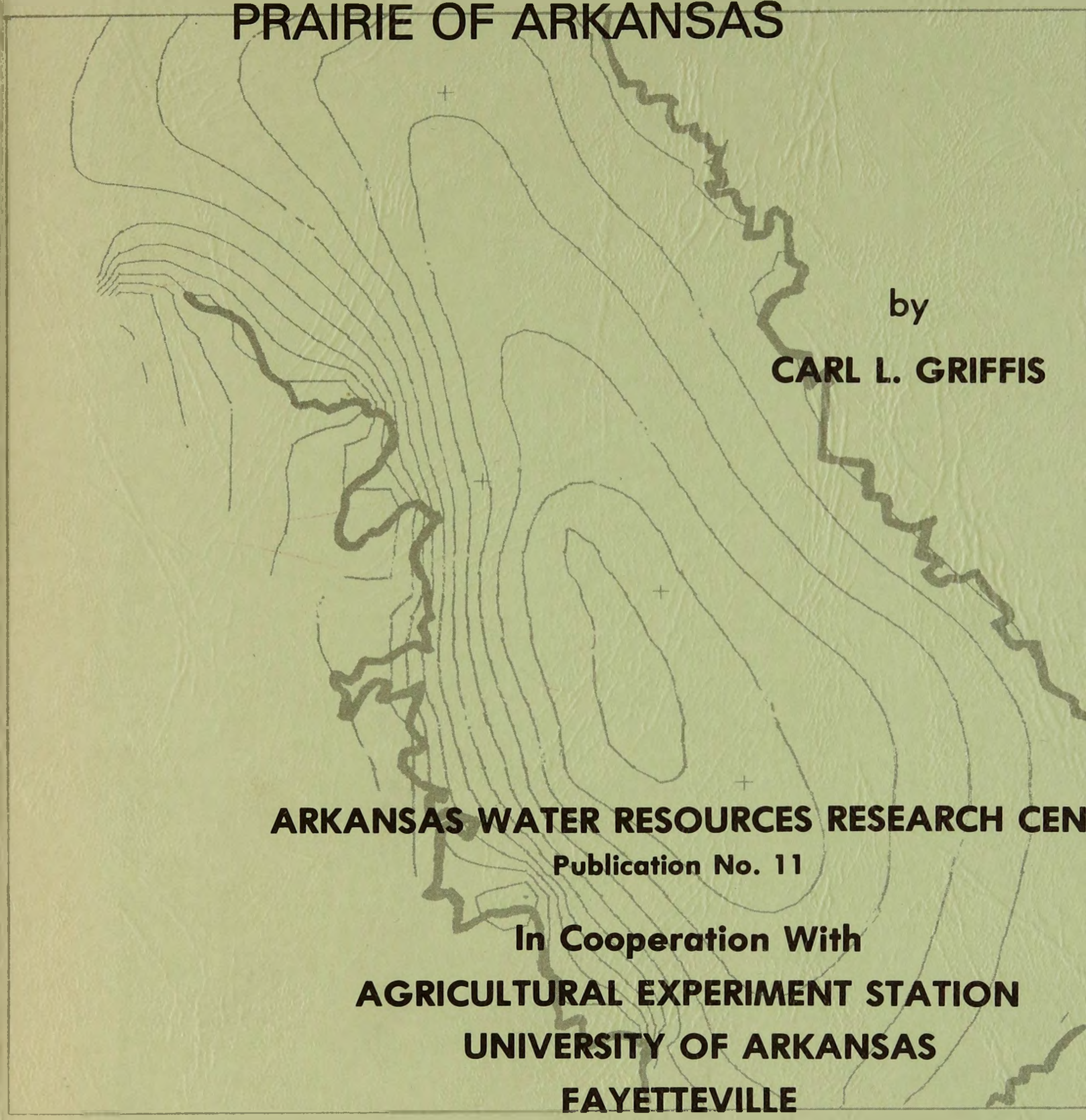
GROUNDWATER — SURFACE WATER INTEGRATION STUDY IN THE GRAND PRAIRIE OF ARKANSAS



by

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ARKANSAS WATER RESOURCES RESEARCH CENTER

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GROUNDWATER - SURFACE WATER INTEGRATION STUDY

IN THE GRAND PRAIRIE REGION OF ARKANSAS

BY

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1972

ABSTRACT

A mathematical model of the Quaternary Aquifer of the Grand Prairie, Arkansas was developed and used to evaluate a variety of methods of artificially recharging this aquifer. In addition, the model was used to evaluate the impact of various levels of water management and the probable movement of artificially recharged water in the aquifer.

Improved water management and the use of recharge wells were the two alternatives that showed the most promise as potential solutions. The rate of movement of recharged water was determined by the model to be 300 ft./year under a gradient of 16 ft./mile.

ACKNOWLEDGMENT

The work upon which this report is based was supported in part with funds provided by the Office of Water Resources Research, U. S. Department of the Interior, under Grant Number A-010-ARK, as authorized under the Water Resources Research Act of 1964, P. L. 88-379 as amended by P. L. 89-404, and in part by The University of Arkansas Agricultural Experiment Station.

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INTRODUCTION

The Grand Prairie is located in east-central Arkansas between the White River and Bayou Meto, Figure 1. It is primarily an agricultural area with rice being the major crop. Rice requires a considerable amount of water to grow and a majority of the water for this purpose is pumped from underground through wells. This is done because the farmers are reluctant to convert their valuable farm land to reservoirs and only a few have access to rivers or bayous. As a result, the supply of water in the water-bearing strata underground is being depleted faster than it is being naturally replaced. For this reason, some means of artificially replenishing the water in the aquifer is needed.

Artificial recharge is the movement of water via man-made improvements from the surface of the earth to water bearing strata underground where it may be stored for future use. The need for this is greatest in areas where the major source of water is underground and where the supply of groundwater is being depleted faster than it is being naturally replenished. The Grand Prairie Region of Arkansas is such an area.

There are several methods of artificial recharge. These include: surface spreading through lakes, ponds, basins, ditches, etc., where recharge water percolates slowly downward to the water table; recharge pits excavated down to permeable material and presenting relatively large areas through which the water can percolate; and recharge wells which penetrate into the water-bearing strata.

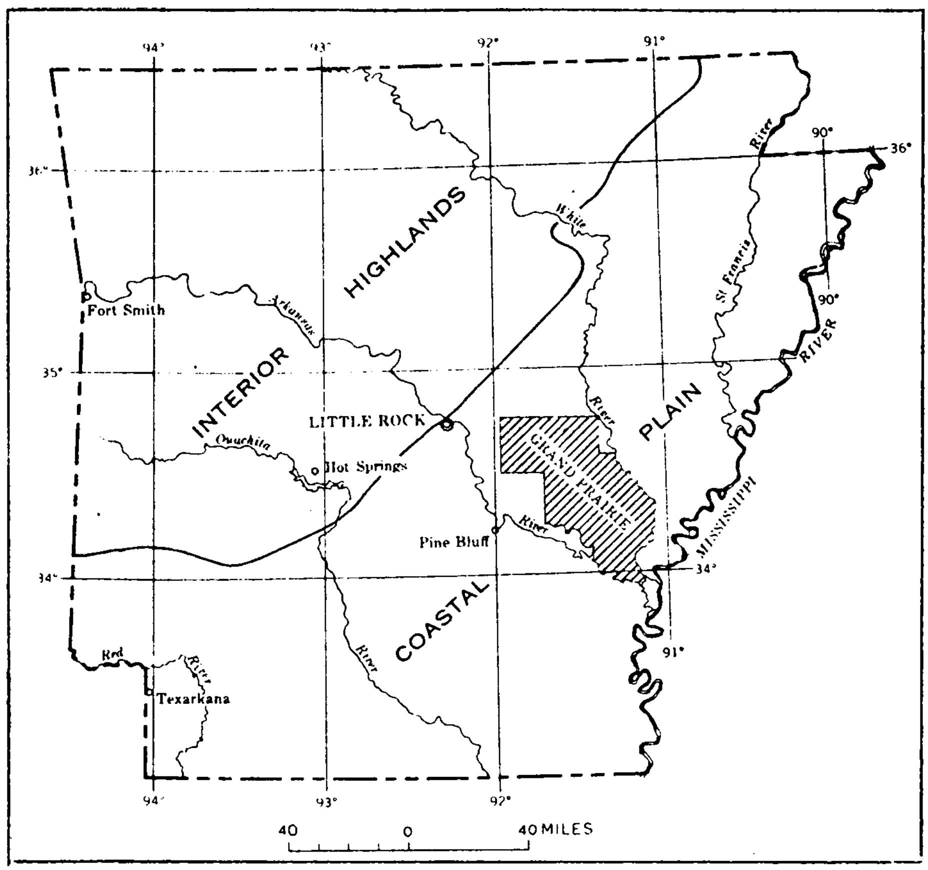


Figure 1. Map Showing Location of Grand Prairie

One of the purposes of this study was to investigate the possibility of dredging Bayou Meto to encourage natural infiltration. An important part of the investigation was the development of a mathematical model for the Quaternary aquifer of the Grand Prairie.

Development of the Mathematical Model

In order to develop the computer program to model the aquifer, the surface of the Prairie between White River and Bayou Meto was divided into a set of unit areas. The areas are approximately one square mile, and their boundaries were chosen to coincide with the section lines of the Federal Land Survey.

Each of these areas subtends a flow volume in the aquifer, bounded at top and bottom by the vertical limits of the aquifer. Figure 2 shows the typical flow volume which was used to derive the basic flow equation.

The fundamental mass conservation equation can be written:

$$\text{Accumulation} = \text{Input} - \text{Output} \tag{1}$$

In a length of time, Δt, the accumulation of water in one of the flow volumes could be determined as follows:

$$\text{Accumulation} = S\ (\Delta H)\ (\Delta X)\ (\Delta Y) \tag{2}$$

where S is the storage coefficient = 0.3 (Engler et al, 1963)

H is the elevation of the piezometric surface above sea level

ΔH is the incremental change in the elevation of the piezometric surface in time Δt

ΔX is the incremental distance in the X direction = 1 mile

and ΔY is the incremental change in the Y direction = 1 mile

The rate of flow into the west face of the flow volume can be calculated using Darcy's law:

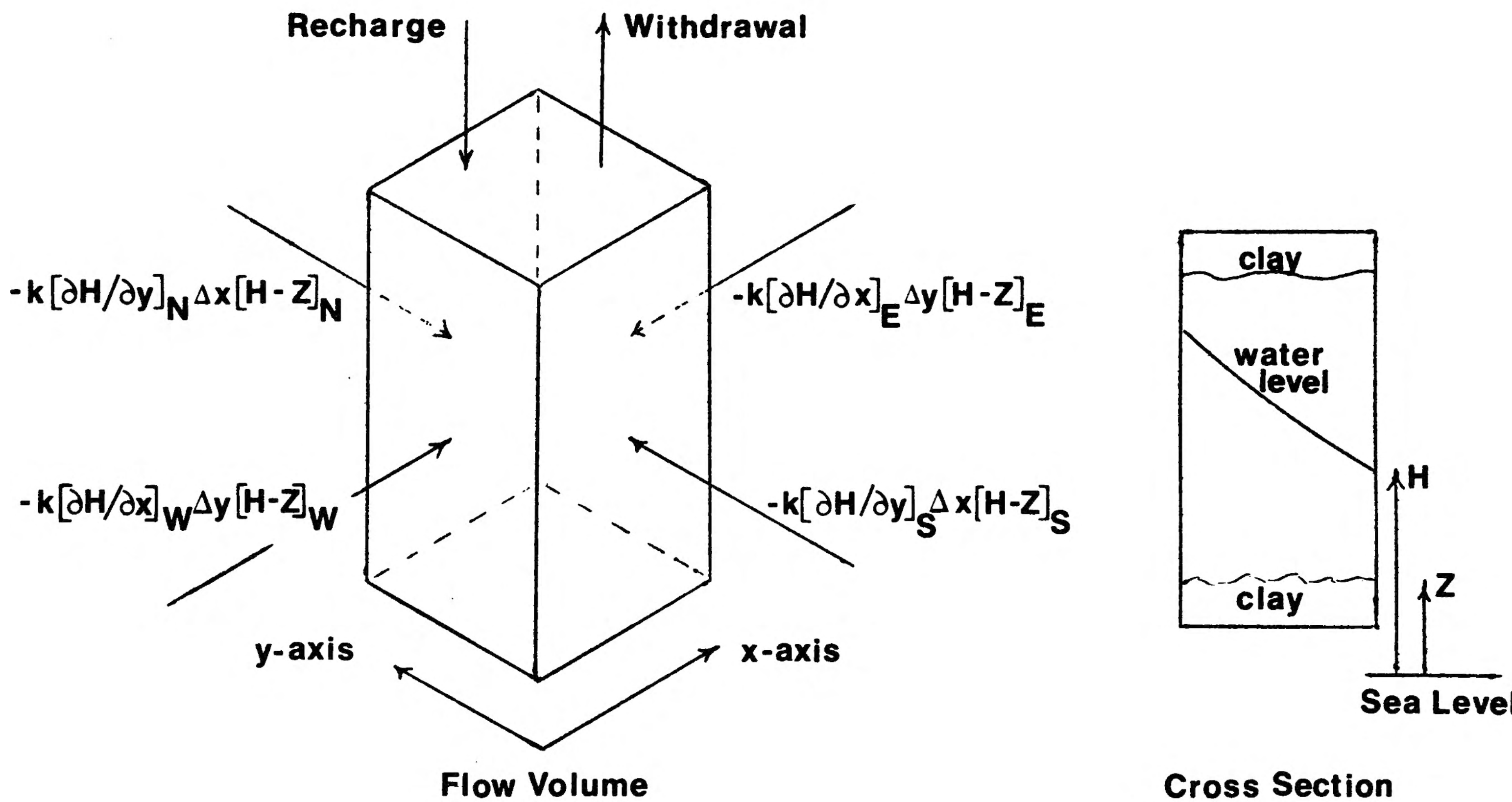


Figure 2. Typical Flow Volume

$$q_W = -k\ (\partial H/\partial x)_W \Delta y\ (H-Z)_W \tag{3}$$

where q_W is the flow into the west face

k is the permeability = 267 ft/day (Engler, et al, 1963)

and Z is the elevation of the bottom of the aquifer. (Thus, H-Z is the height of the flow volume.)

Similar equations can be written for flow through each of the other vertical faces.

Combining these terms leads to Equation 4:

$$\begin{aligned} S\Delta H\Delta y\Delta x = & -k(\partial H/\partial x)_W \Delta y(H-Z)_W \Delta t + k(\partial H/\partial x)_E \Delta y(H-Z)_E \Delta t \\ & -k(\partial H/\partial y)_S \Delta x(H-Z)_S \Delta t + k(\partial H/\partial y)_N \Delta x(H-Z)_N \Delta t \\ & + \text{Recharge Rate}(\Delta t) - \text{Withdrawal Rate}(\Delta t) \end{aligned} \tag{4}$$

where Recharge Rate is the rate of injection of water from the surface

and Withdrawal Rate is the rate of withdrawal due to pumping

Dividing by $\Delta t \Delta X \Delta y$ and letting these incremental values decrease toward zero, one can obtain:

$$S(\partial H/\partial t) = k\left[\partial/\partial x(\partial H/\partial x\ (H-Z)\ ) + \partial/\partial y(\partial H/\partial y\ (H-Z)\ )\right] + \text{Recharge Rate} - \text{Withdrawal Rate} \tag{5}$$

Thus, we have an equation which can be used to describe the response of the piezometric surface to various stimuli.

An approximate solution to Equation 5 can be obtained by finite difference techniques, starting with Equation 4. Expressing ΔH explicitly and rewriting Equation 4 one obtains:

$$H_2 \cong H_1 - k/S\,(\partial H/\partial x)_W(H-Z)_W\Delta t/\Delta x \;+\; k/S\,(\partial H/\partial x)_E(H-Z)_E\Delta t/\Delta x$$
$$- k/S\,(\partial H/\partial y)_S(H-Z)_S\Delta t/\Delta y \;+\; k/S\,(\partial H/\partial y)_N(H-Z)_N\Delta t/\Delta y \qquad 6$$
$$+ \text{Recharge Rate}(\Delta t/S) \qquad - \text{Withdrawal Rate}(\Delta t/S)$$

where H_1 is the water level at the beginning of a time interval

and H_2 is the water level at the end of the time interval

The partial derivatives in Equation 6 can be approximated:

$$(\partial H/\partial X)_W = \frac{H_X - H_{X-\Delta X}}{\Delta X} \qquad 7$$

Making this approximation for all of the partial derivatives, one has:

$$H_2 \cong H_1 - \frac{k}{s}\,\frac{(H-Z)\,\Delta t\,(H_X-H_{X-\Delta X})}{\Delta X^2} + \frac{k}{s}\,\frac{(H-Z)\,\Delta t\,(H_{X+\Delta X} - H_X)}{\Delta X^2}$$
$$- \frac{k}{s}\,\frac{(H-Z)\,\Delta t\,(H_Y-H_{Y-\Delta Y})}{\Delta Y^2} + \frac{k}{s}\,\frac{(H-Z)\,\Delta t\,(H_{Y+\Delta Y} - H_Y)}{\Delta Y^2} \qquad 8$$
$$+ \text{ Recharge Rate }(\Delta t/S) - \text{Withdrawal Rate }(\Delta t/S)$$

An examination of this equation shows that the left hand side is evaluated at the end of the time interval, Δt, while the right hand side contains many terms in H, evaluated at some unspecified time. One solution to the evaluation of these terms is to use the average values of H over the time interval, Δt.

If Δt is small, and the rate of change of H is small, then the arithmetic average of H over the time interval will be satisfactory.

After making this substitution, Equation 8 becomes:

$$H_2 \cong H_1 - \frac{k}{s}\,\frac{(\bar{H}-Z)\,\Delta t\,(\bar{H}_X-\bar{H}_{X-\Delta X})}{\Delta X^2} + \frac{k}{s}\,\frac{(\bar{H}-Z)\,\Delta t\,(\bar{H}_{X+\Delta X} - \bar{H}_X)}{\Delta X^2}$$
$$- \frac{k}{s}\,\frac{(\bar{H}-Z)\,\Delta t\,(\bar{H}_Y-\bar{H}_{Y-\Delta Y})}{\Delta Y^2} + \frac{k}{s}\,\frac{(\bar{H}-Z)\,\Delta t\,(\bar{H}_{Y+\Delta Y} - \bar{H}_Y)}{\Delta Y^2} \qquad 9$$
$$+ \text{ Recharge Rate }(\Delta t/S) - \text{Withdrawal Rate }(\Delta t/S)$$

Where $\bar{H}$ is $\dfrac{H_2 + H_1}{2}$

Since both sides of this equation contain the unknown values for which we seek, it was necessary to employ an iterative technique for solution. The method of solution which was followed is described below.

The Spring of 1939 was chosen as the starting time for the solution. Initial water table elevations, values for permeability and storage coefficients, and elevations of the bottom of the aquifer were determined for each flow volume from previous measurements (Sniegocki, 1969). Because of the heavy clay overburden, the rate of infiltration from the surface into each flow volume was assumed to be zero, except at the locations of the artificial recharge wells.

It was possible to estimate withdrawal rates for each flow volume from previous estimates of the quantity of water withdrawn annually for the entire Prairie (Engler et al, 1945). Withdrawal rates for each flow volume were allocated in proportion to the amount of rice grown in that region.

The boundaries chosen were the Arkansas River on the south, the White River on the east, Bayou Meto on the west, and the north edge of Township 2 North on the north. Water table elevations in those flow volumes which fell on these irregular boundaries were not computed from Equation 9, but were adjusted in each time interval to correspond to historical values. Equation 9 was then solved at each interior point using the Jacobi method of iteration (Stanton, 1961). A stable solution was obtained with a time increment of one month.

Verification of the Model

After the development of the model it was necessary to verify that it was an adequate representation of the physical system. The verification was attempted as follows. The computer model was given measured water levels for 1939 and asked to predict what the water levels would be twenty years later. The results of the computer prediction are plotted in Figure 3 with the water levels that were measured in that same year, 1959. In addition, a cross-sectional view is shown in Figure 4. These two figures show that the computer model is a reliable simulation of the Quaternary aquifer and can be used to study alternative artificial recharge schemes.

Evaluating Alternatives: The Mathematical Model as a Tool

The first alternative considered was the dredging of Bayou Meto to encourage natural infiltration. The computer was programmed to start at 1939 and predict the water levels in 1959, assuming that during the twenty year period the groundwater level along Bayou Meto was at the surface of the ground. This would imply that infiltration was proceeding at the maximum possible rate. It also assumes that a massive technological effort could be mounted in order to prevent plugging of any part of the 65 mile reach of the bayou with sediment.

The results of the computer prediction are shown in Figure 5. A comparison with Figure 3 shows that the dredging of the Bayou would have a pronounced effect upon the water levels along the eastern edge of the Prairie, However, there would still be a serious shortage of groundwater in the central and western parts of the area. It appears to be a case of applying the remedy too far from the center of the problem.

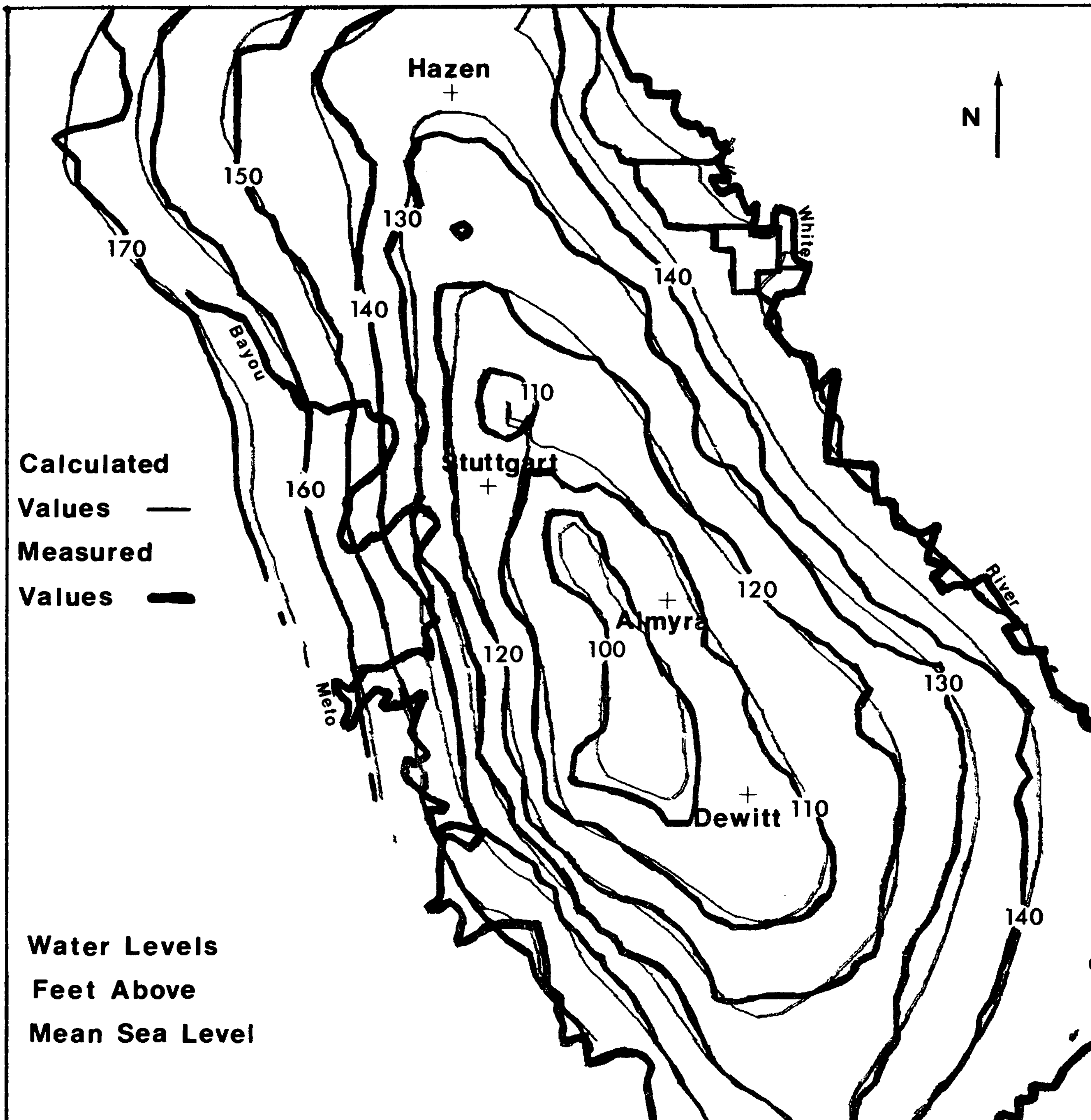


Figure 3. A Comparison of the Contour Map Calculated by the Computer and the Contour Map Based on Measured Water Levels - Spring, 1959

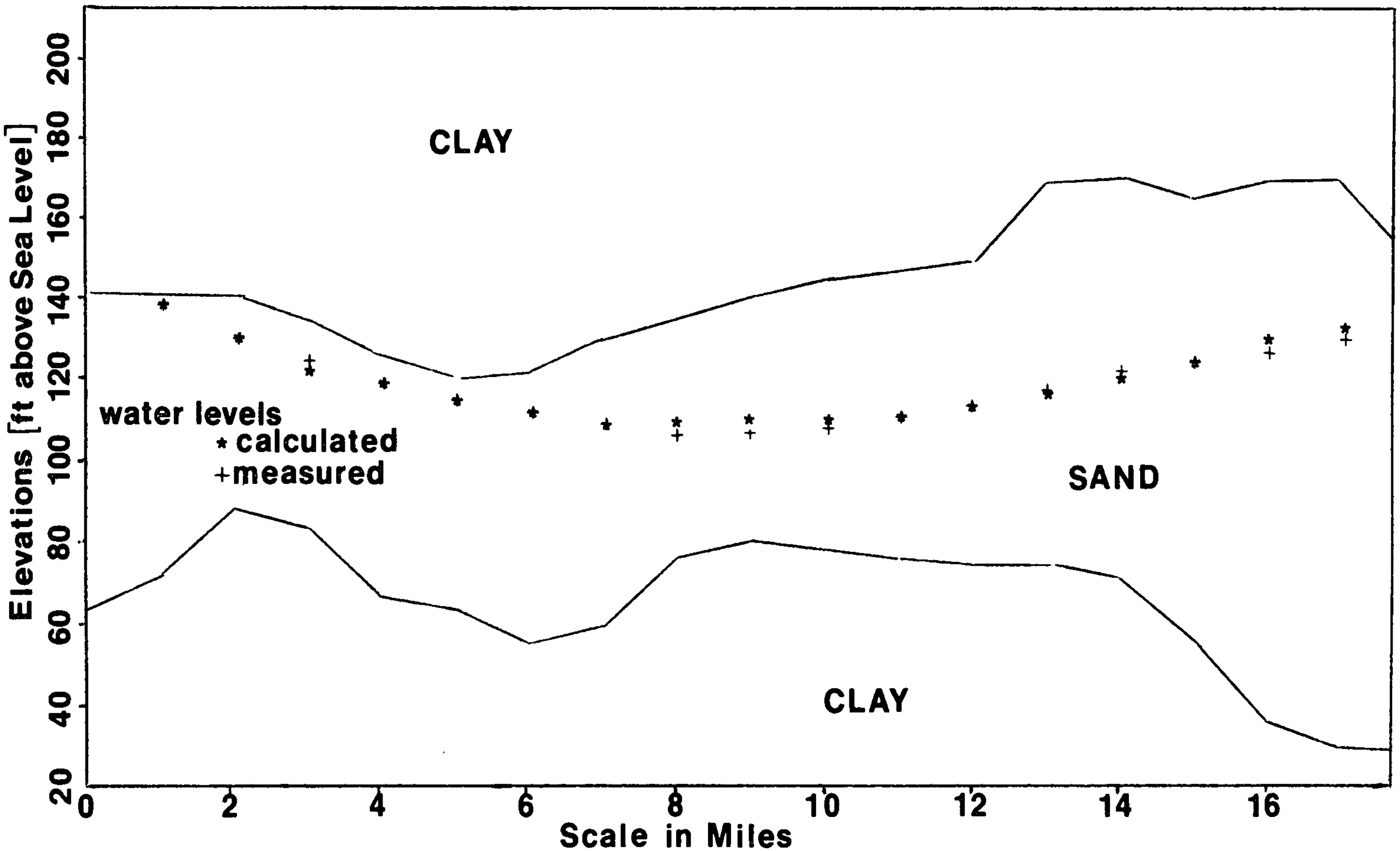


Figure 4. Cross-section of Aquifer near Stuttgart

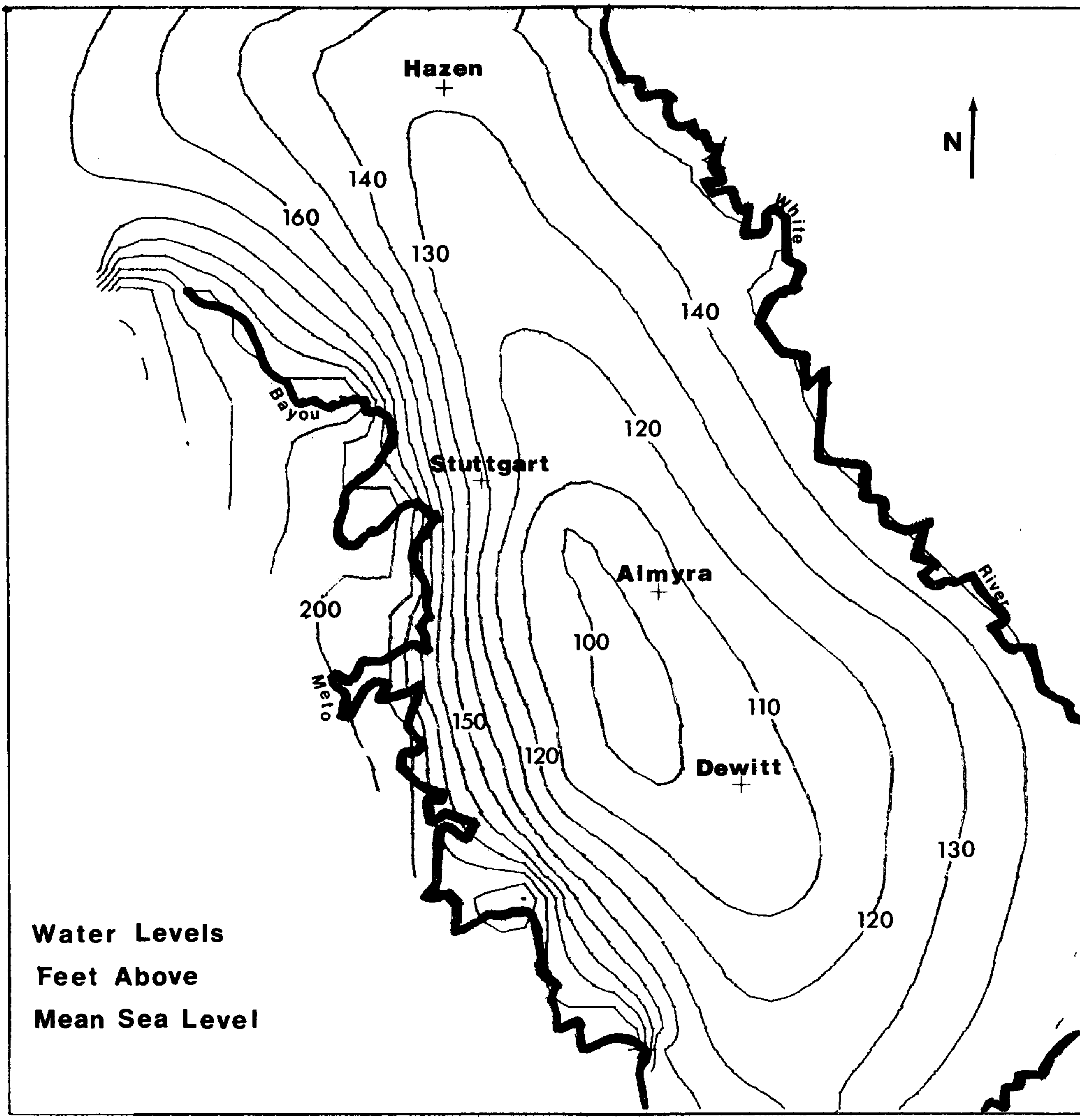


Figure 5. Projected Contour Map, Assuming Deep Dredging of Bayou Meto - Spring, 1959

Another potential solution to the water shortage problem is the use of artificial recharge wells. The effects of three of these wells recharging at a rate of 5000 gpm during the twenty-year period 1939 to 1959 are shown in Figure 6. The locations of the hypothetical wells are indicated by asterisks.

A comparison of Figure 6 with previous figures shows that the three wells would have had a significant effect. The results are actually a conservative estimate of the effectiveness of the wells since the water levels along the boundaries were assumed to fall at the historical rate. The wells have an added advantage in that they can be located where the water depletion is most severe.

Next, the model was used to evaluate the possible effects on the aquifer if nothing were done to solve water depletion problems. This was accomplished by entering the water table elevations for 1959 and asking the model to predict the elevations for 1979. The withdrawal rate for each section was assumed to be the average withdrawal rate in that section for the twenty year period 1939 to 1959. Special handling was required for the boundaries since the sources of recharge occur there. One alternative was to assume that the aquifer would reach a stable condition in the simulation period. In this case, all of the water levels would reach a constant value including the boundaries. Another possibility is that the water levels, including those on the boundaries, would continue to decline during the entire simulation period.

Figure 7 shows the prediction of the model based upon the assumption that the water levels along the boundaries would remain fixed at the 1959 levels. Figure 8 shows the predictions of the model, assuming that the water levels along the boundaries would continue to decline at the same average rate as during the previous twenty years.

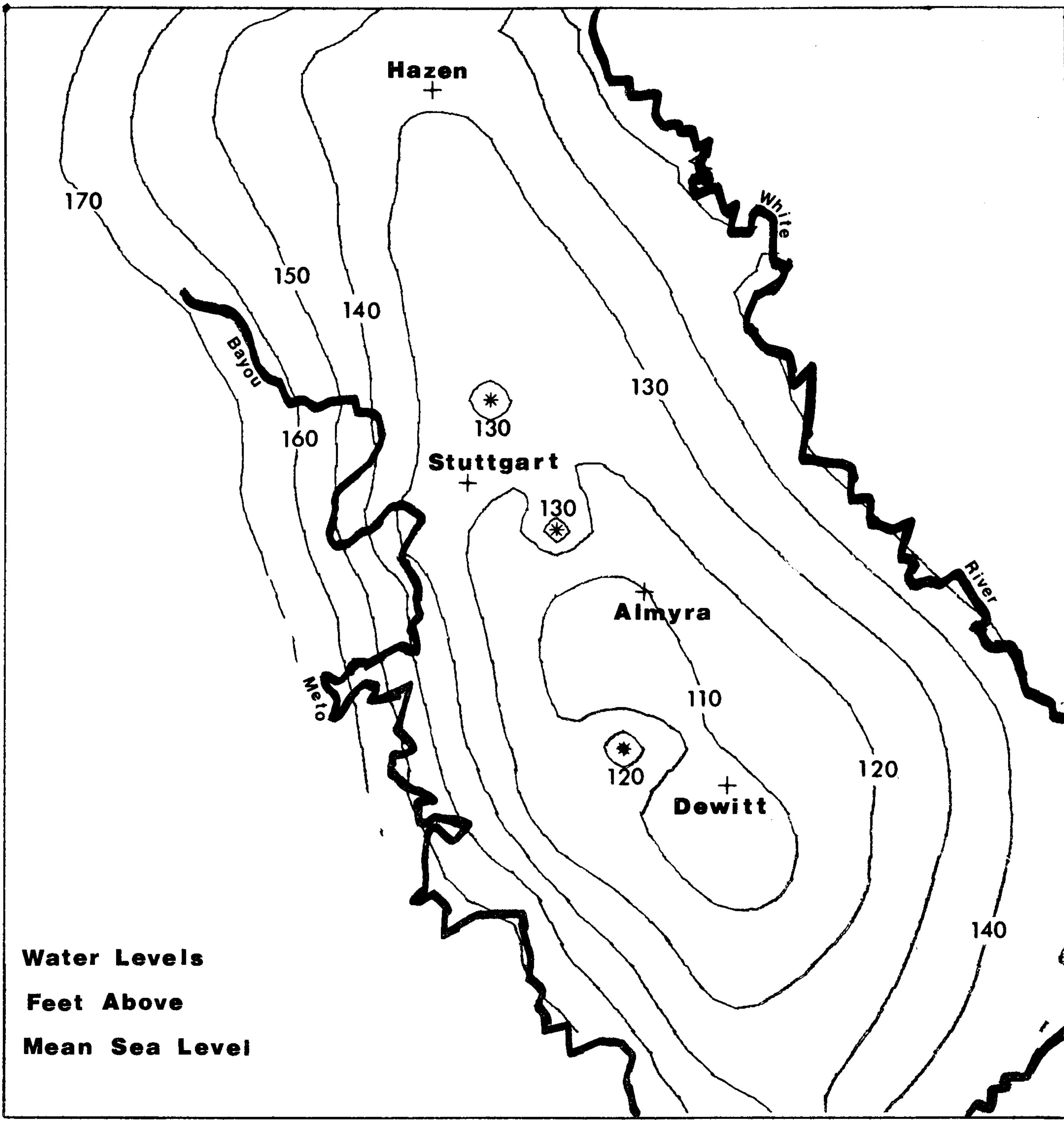


Figure 6. Projected Contour Map, Assuming Operation of Recharge Wells

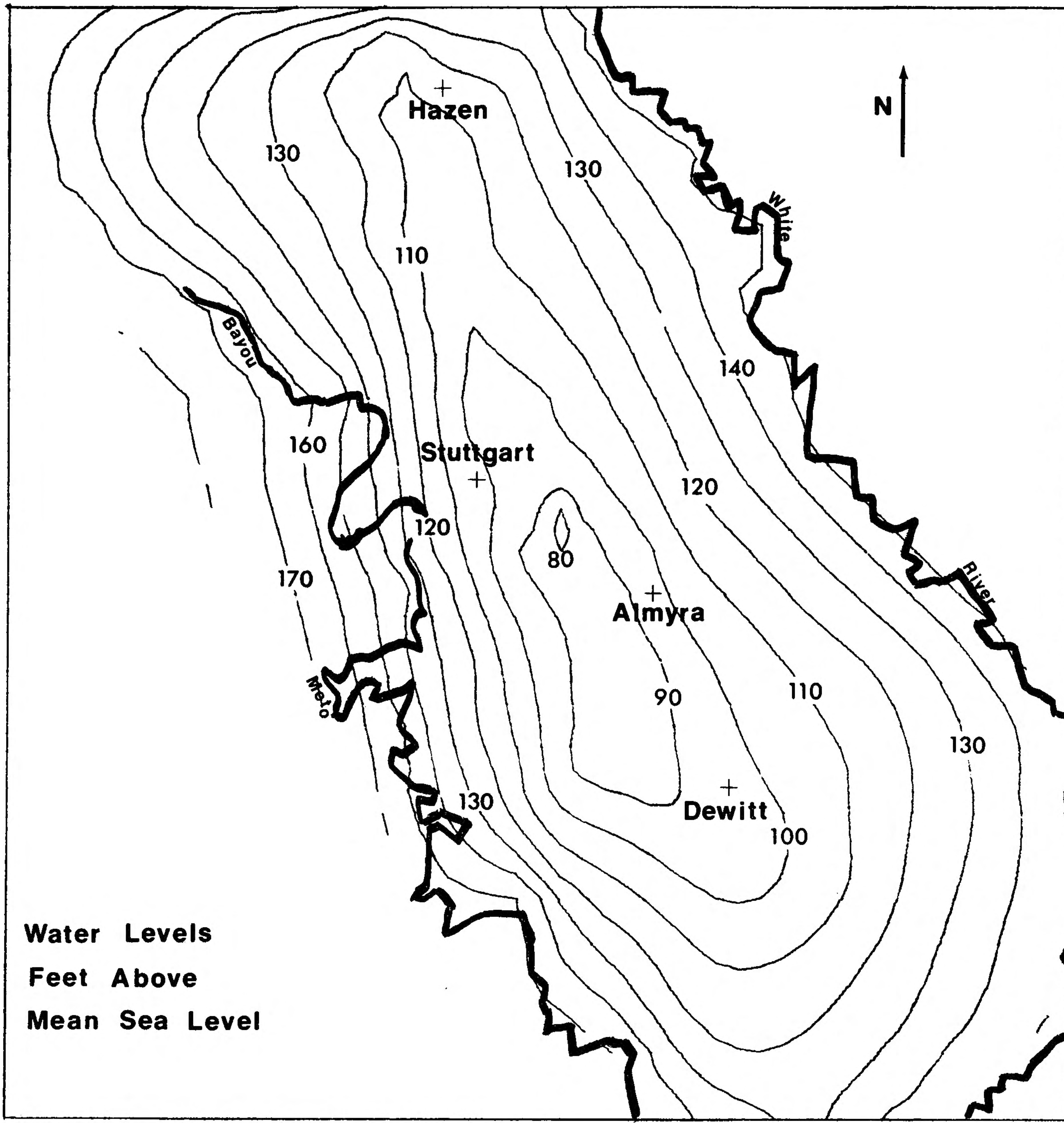


Figure 7. Result of Inaction, Fixed Boundaries - Spring, 1979

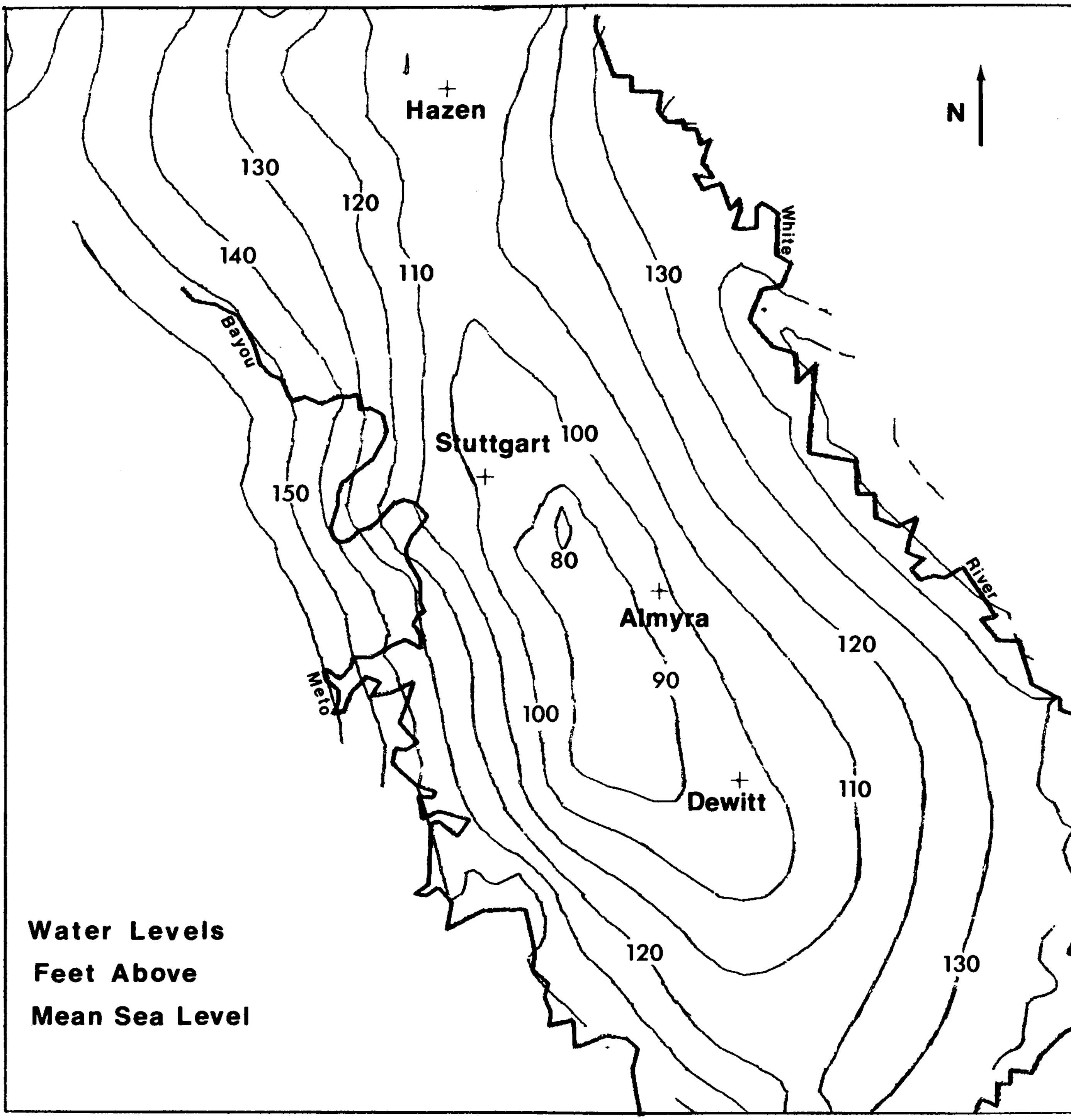


Figure 8. Probable Result of Inaction - Spring, 1979

A comparison of the two figures shows that a stable condition was not reached during the simulation period. Therefore, it was concluded that Figure 8 is the more probable result of inaction.

The model was next employed to determine the level of water management that would be required to achieve a stable water table. The water table as it existed in 1959 was arbitrarily chosen as the desired condition. Since a stable water table was the goal, the water levels along the boundaries were fixed at the 1959 levels.

Figure 9 is the prediction of the model, assuming that a thirty percent reduction in the withdrawal rates was achieved. Comparison with Figure 3 shows that a stable condition was not obtained.

Figure 10 shows the prediction of the model assuming that a fifty percent reduction in withdrawal rates was possible. Comparison with Figure 3 shows that a slight improvement would result in the central Prairie and a slight worsening near the boundaries. Thus, a fifty percent reduction appears to be the critical value to consider when attempting to conserve the groundwater.

The question of the feasibility of achieving this level of water conservati(remains open. Recent research, however, has shown that the usage of groundwater can be reduced by almost 30% by improved water management practices (Ferguson, 1972).

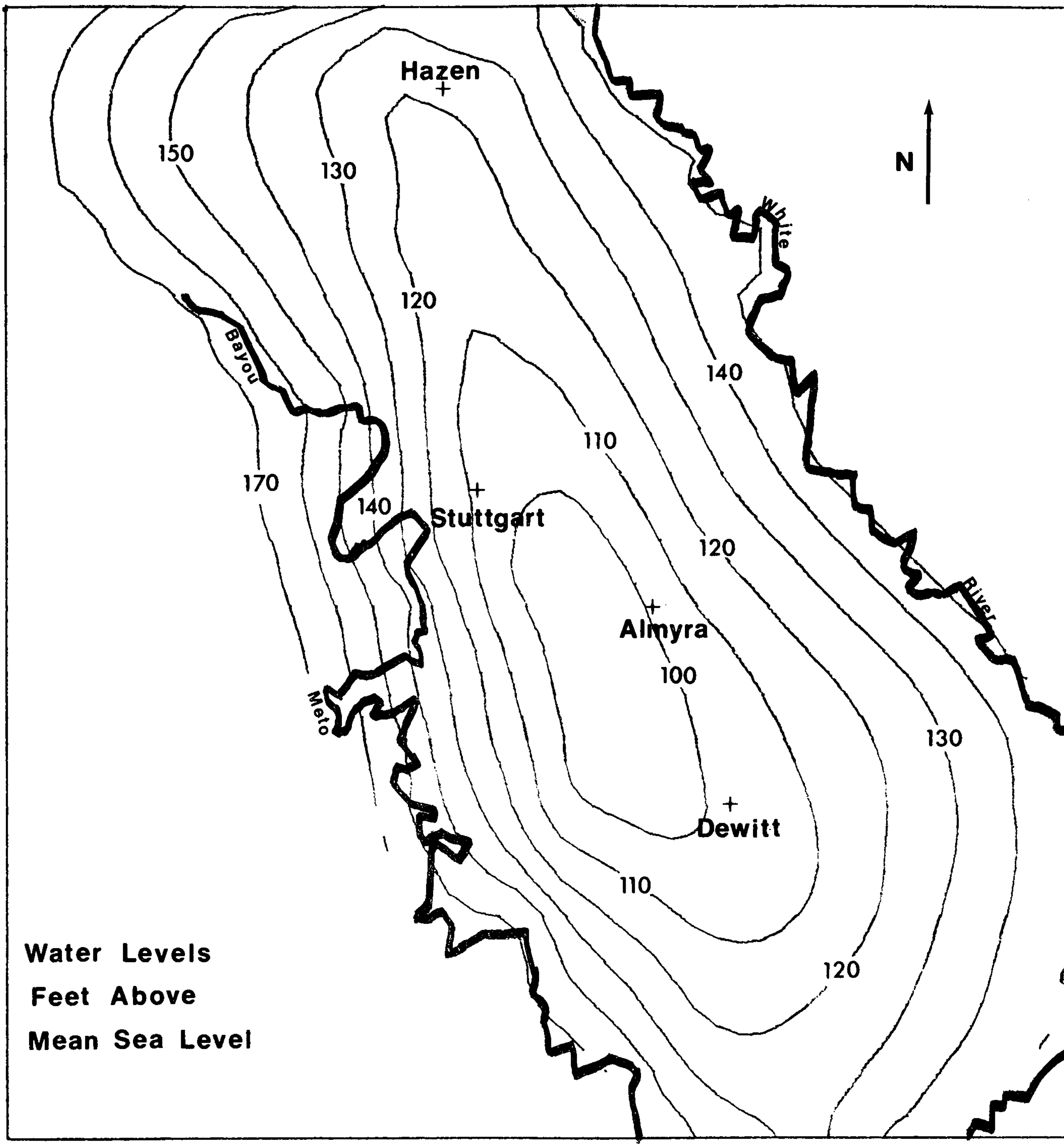


Figure 9. Result of Thirty Percent Reduction in Groundwater Consumption - Spring, 1979

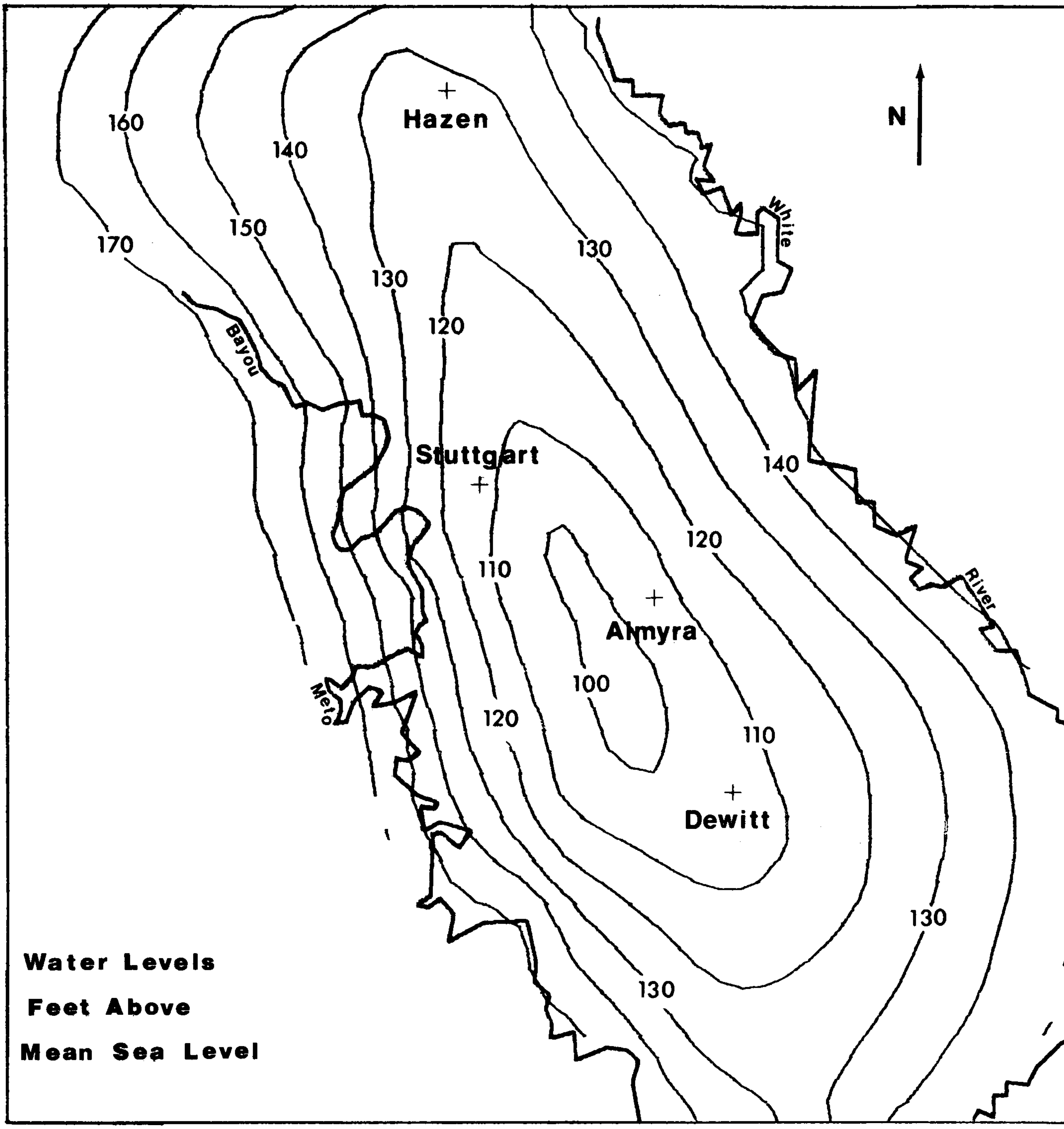


Figure 10. Result of Fifty Percent Reduction in Groundwater Consumption - Spring, 1979

Movement of Artificially Recharged Water in the Quaternary Aquifer

Another area of concern in studies of artificial recharge is the potential pollution of the groundwater. A revised version of the Mathematical Model has been used to study the movement of artificially recharged water in the aquifer (Turpin et al, 1972). The purpose of the investigation was to provide a means of identifying and locating potential pollution caused by a specific recharge well. This was done by determining the radial spread of water from the recharge well into the aquifer, and subsequentially into adjacent irrigation wells.

A nine-square-mile area centered at the Rice Branch Experiment Station, near Stuttgart, was selected for the study. Bases and assumptions were:

1. The water table elevations of 1959 were chosen as a basis, and elevations at the boundaries were held constant at these values.
2. A total of 4150 acre-feet per year of groundwater were consumed for irrigation of 2300 acres of rice in the area.
3. A single recharge well was used with a recharge rate of roughly 4 acre-feet per day.

Water table elevations after three years with no recharge and with the single recharge well, respectively, are compared in Figures 11 and 12.

Movement of the recharge water in the aquifer is demonstrated by Figures 13 and 14. Each symbol on the figures represents approximately 50 acre-feet of water recharged. The locations of the symbols show the direction and rate of movement of the recharged water. During the first 100 days, the movement of the recharge water is to the south and west. However, during the second 100 day period, flow occurs in all directions away from the recharge well because of its increased cone of elevation (Figure 3).

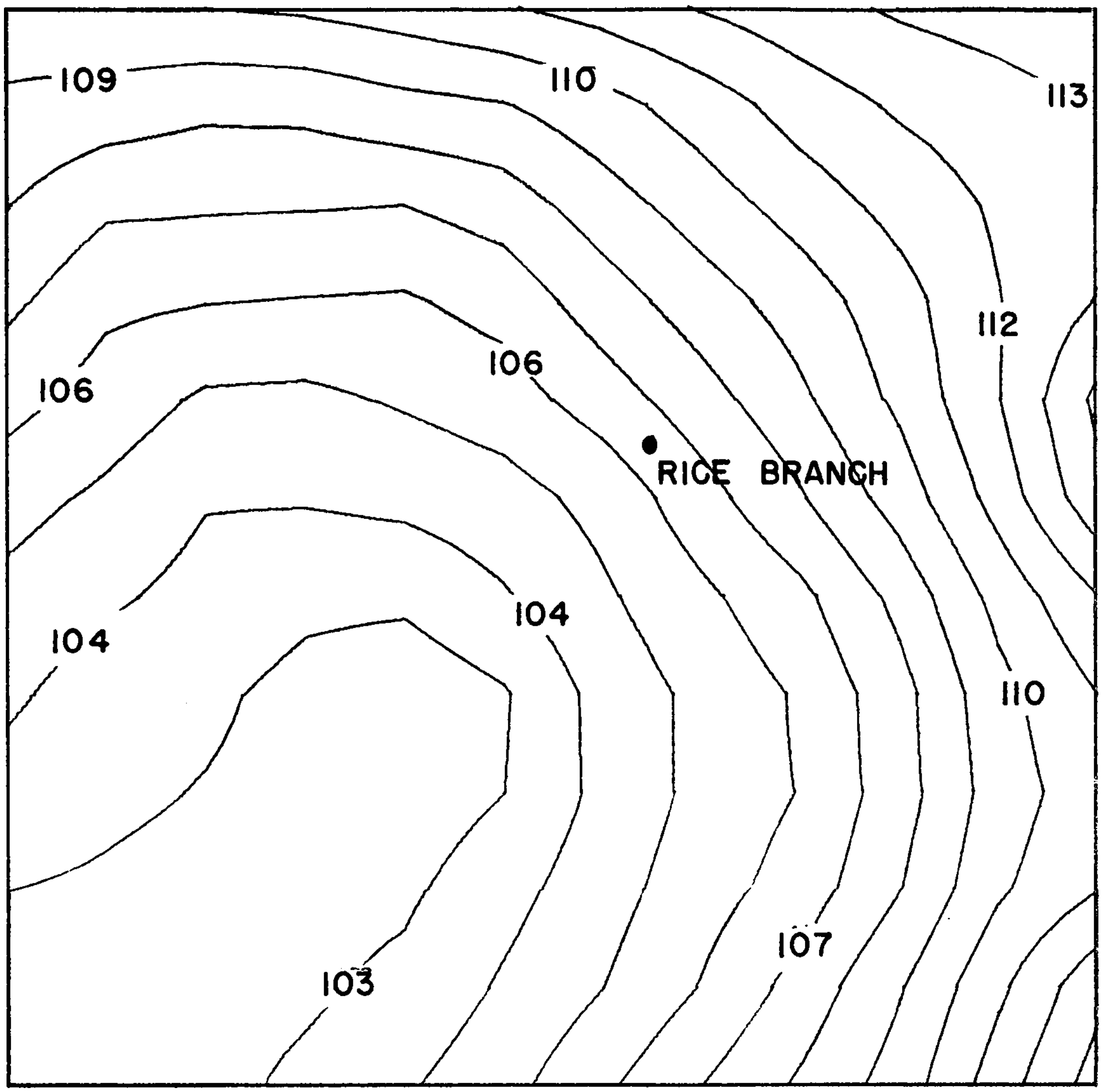
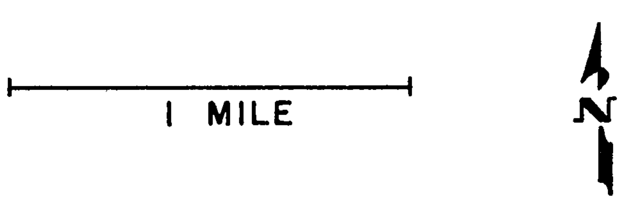


FIGURE 11: WATER TABLE AFTER THREE YEARS WITH NO RECHARGE



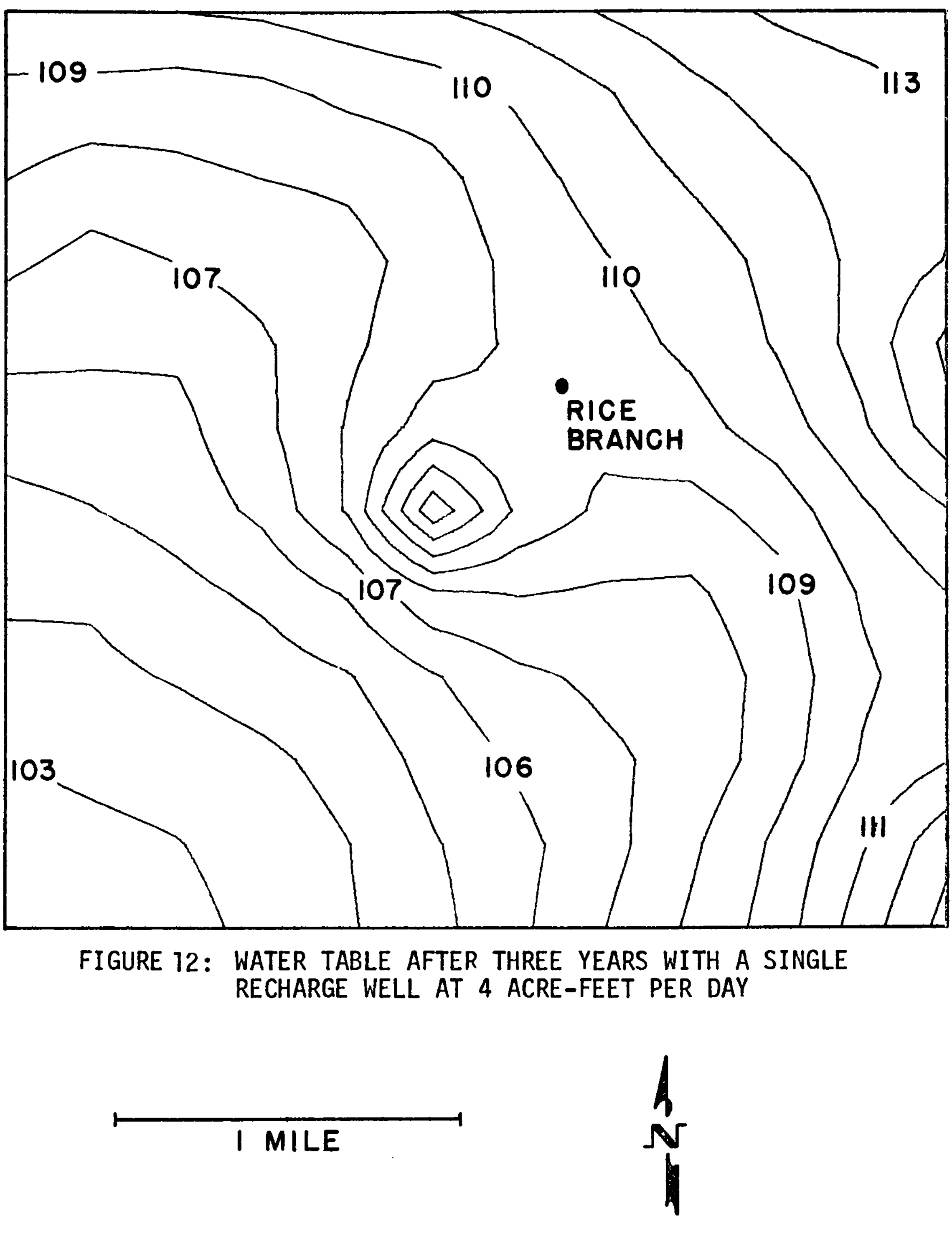


FIGURE 12: WATER TABLE AFTER THREE YEARS WITH A SINGLE
RECHARGE WELL AT 4 ACRE-FEET PER DAY

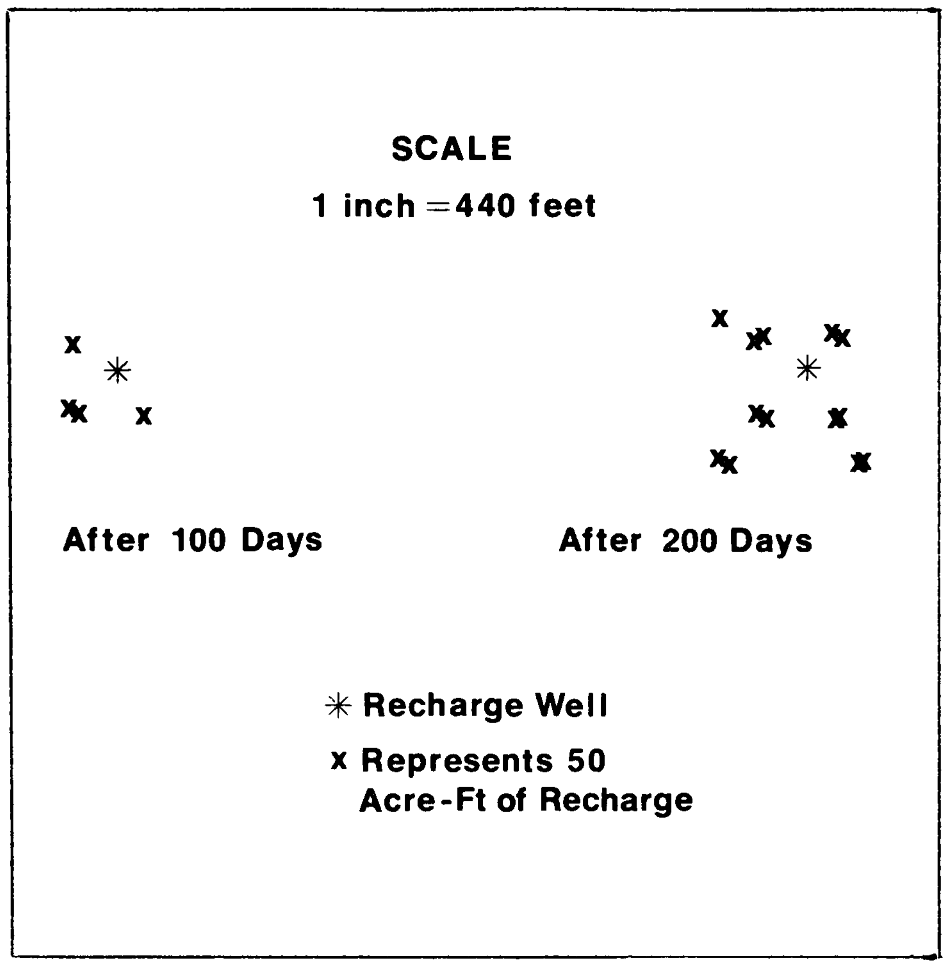


Figure 13. Movement of Artificially Recharged Water in the Aquifer

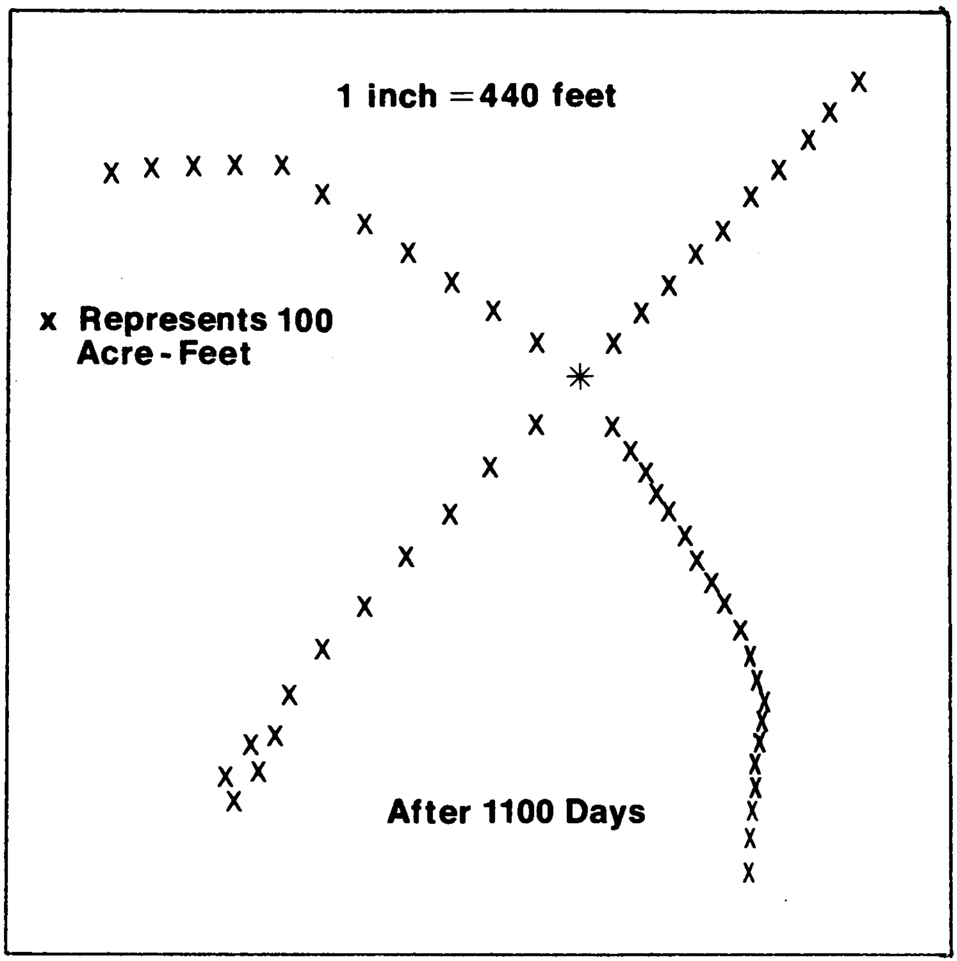


Figure 14. Movement of Artificially Recharged Water in the Aquifer - Extended Period

Location of the water from the single recharge well at extended periods of time is shown by Figure 4 for 1100 days (3 years). Sumbols representing recharge water which comes into the domain of an irrigation well are deleted. Radial spread of the recharge water is approximately 300 feet per year under a gradient of 16 feet per mile.

Conclusions

Of the alternatives considered only two appear to offer promise: artificial recharge wells, and water management to reduce consumption.

The modification of the model has produced a useful tool for the study of the effects of artificial recharge on the quality of the water in the Quaternary aquifer.

Recommendations

The technological problems involved in recharging through wells must be overcome if this is to be an economically feasible solution. Research is particularly important in the area of water treatment prior to recharge. It is recommended that this research be undertaken.

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APPENDIX

A Listing of the PL/I Program of the Mathematical Model

```
/* WATER RESOURCES FLOW MODEL
       DEFINITION SECTION
            A                 =    FLOW INTO SECTION FROM THE SOUTH
            B                 =    FLOW INTO SECTION FROM THE WEST
            BUMP              =    FLOATING POINT VARIABLE USED TO REPRESENT ITER
                                      IN CALCULATIONS
            C                      FLOW INTO SECTION FROM THE NORTH
            D                      FLOW INTO SECTION FROM THE EAST
            DELT                   TIME INCREMENT IN DAYS
            DELX                   THE SQUARE OF THE DISTANCE INCREMENT IN FEET
            DELY                   THE SQUARE OF THE DISTANCE INCREMENT IN FEET
            F                      FLOATING POINT VARIABLE USED TO REPRESENT
                                      THE RATIO OF THE ACRES OF RICE IRRIGATED
                                      IN THE CURRENT YEAR TO THE ACRES OF RICE
                                      IRRIGATED IN 1939
            G                      A VECTOR CONTAINING ALL OF THE RATIOS REFERRED
                                      TO ABOVE
            H                      THE ARRAY OF VALUES OF THE ELEVATIONS OF THE
                                      PIEZOMETRIC SURFACE. THE THIRD SUBSCRIPT
                                      IS USED AS FOLLOWS:
                                         1 = CALCULATED VALUES
                                         2 = CALCULATED VALUES DURING ITERATION
                                         3 = TEMPORARY STORAGE OF H(I,J,2) VALUES
                                               FOR COMPARISON WITH NEXT ITERATION
                                         4 = VALUES FOR 1959
                                         5 = VALUES FOR 1939
            HYDRO             =    A COMBINATION OF THE FLOW AREA, THE TIME
                                      INCREMENT, AND THE VALUE OF TC
            IN                =    THE ARRAY OF INPUT RATES DUE TO RECHARGE
            ITER              =    THE NUMBER OF TIME STEPS TO BE TAKEN
            ITEST             =    A COUNTER TO SEE IF CONVERGENCE IS ACHIEVED
                                      IN 20 TRIES OR FEWER
            JUMP              =    A COUNTER FOR MONTHS
            LEFT              =    THE RELATIVE LOCATION OF THE WEST BOUNDARY OF
                                      THE PRAIRIE
            LRT               =    THE RELATIVE LOCATION OF THE EAST BOUNDARY OF
                                      THE PRAIRIE
            N1,N2,N3,N4       =    THE VECTORS CONTAINING THE LOCATION OF THE
                                      BOUNDARIES OF THE PRAIRIE
            NCOUNT            =    A COUNTER FOR THE NUMBER OF TIME INCREMENTS
                                      ACCOMPLISHED
            NSUB              = A COUNTER FOR THE NUMBER OF YEARS ACCOMPLISHED
            OOPS              =    A TEST VARIABLE FOR CONVERGENCE
            OUT               =    THE ARRAY OF WITHDRAWAL RATES
            SANAVE            =    THE AVERAGE ELEVATION OF THE TOP OF THE
                                      AQUIFER NEAR THE POINT UNDER CONSIDERATION
            SAND              =    THE ARRAY OF ELEVATIONS OF THE TOP OF THE
                                      AQUIFER
            SWITCH            =    A VARIABLE WHICH TURNS ON THE WITHDRAWAL RATES
                                      FOR THREE MONTHS, THEN OFF
            TC                =    STORAGE COEFFICIENT/PERMEABILITY
            Z                 =    THE ARRAY OF ELEVATIONS OF THE BOTTOM OF THE
                                      AQUIFER
            ZAVE              =    THE AVERAGE VALUE OF Z NEAR THE POINT UNDER
                                      CONSIDERATION
      */
FLOW: PROCEDURE RECORDER OPTIONS(MAIN) :
     DECLARE
          H(49,52,5) FLOAT DECIMAL INITIAL( (12740) 0.0 ) ,
          ( OUT(49,52), IN(49,52), SAND(49,52), Z(49,52)) FLOAT DECIMAL ,
          G(20) FIXED(5,4) INITIAL(1., 1.1136, 1.1988, 1.4318, 1.4034,
```

```
            1.4062, 1.409, 1.5738, 1.6761, 1.7102, 1.7784, 1.5113, 1.9829,
            1.9715, 2.017, 2.25,1.659, 1.4545, 1.2897, 1.1761 ) ,
          DELX FLOAT INITIAL( 2.78784E07 ) ,
          DELY FLOAT INITIAL( 2.78784E07 ) ,
          DELT FLOAT INITIAL( 30.42 ) ,
          TC  FLOAT INITIAL(.001122) ,
          N1(52) FIXED DECIMAL INITIAL(
            2,1,1,1,1,1,2,3,3,4,5,5,6,9,11,11,12,13,17,17,16,16,17,19
           ,19,19,19,19,18,18,18,18,18,19,19,19,19,19,19,19,20,25,25,
            25,25,25,26,29,30,30,31,32),
          N2(52) FIXED DECIMAL INITIAL(
                                                 26,1,1,1,1,1,2,3,3,4,5,5
        ,8,10,11,11,12,16,17,17,16,16,18,19,19,19,19,19,18,18,18,18,
            18,19,19,19,19,19,19,19,24,25,25,25,25,25,28,29,30,30,31,42),
          N3(52) FIXED DECIMAL INITIAL(
                    2,27,27,28,29,31,32,32,32,33,35,35,35,34,34,35,
            36,36,36,36,37,38,39,40,41,42,43,44,45,46,46,47,48,49,49,
            49,48,48,48,48,48,48,47,47,47,47,47,46,44,43,43,32),
          N4(52) FIXED DECIMAL INITIAL(
            26,27,27,28,30,31,32,32,32,34,35,35,35,34,34,35,36,36,36,
            36,37,38,39,40,41,42,43,44,45,46,46,47,48,49,49,49,48,48,
            48,48,48,48,47,47,47,47,47,46,45,43,43,42 ),
          SWITCH FLOAT DECIMAL INITIAL(1.),
          ITEST FIXED INITIAL(1),
          NSUB FIXED INITIAL(1),
          JUMP FIXED INITIAL(0),
          NCOUNT FIXED INITIAL(1),
          PUNCH FILE STREAM OUTPUT ;
/* PROGRAM STATEMENTS  */
          GET FILE(SYSIN) EDIT (ITER) ( F(4) ) ;
          BUMP = ITER ;
          DO J = 1 TO 52 ; LEFT = N1(J) ; LRT = N4(J) ;
          GET FILE(SYSIN) SKIP EDIT ( (H(I,J,1) DO I = LEFT TO LRT ))
                          ( (8) F(9,4) , SKIP ) ;
          GET FILE(SYSIN) SKIP EDIT ( (H(I,J,4) DO I = LEFT TO LRT ))
                          ( (8) F(9,4) , SKIP ) ;
          GET FILE(SYSIN) SKIP EDIT ( (SAND(I,J) DO I = LEFT TO LRT ))
                          ( (8) F(9,4) , SKIP ) ;
          GET FILE(SYSIN) SKIP EDIT ( (Z(I,J) DO I = LEFT TO LRT ))
                          ( (8) F(9,4) , SKIP ) ;
          GET FILE(SYSIN) SKIP EDIT( (IN(I,J) DO I = LEFT TO LRT ))
                          ( (8) F(9,4) , SKIP ) ;
          GET FILE(SYSIN) SKIP EDIT ( (OUT(I,J) DO I = LEFT TO LRT ))
                          ( (8) F(9,4) , SKIP ) ;
          DO I = LEFT TO LRT ;
            H(I,J,5), H(I,J,3), H(I,J,2) = H(I,J,1) ; END ; END ;
          OPEN FILE(SYSPRINT) LINESIZE(133) ;
 ON ENDPAGE(SYSPRINT) ;
START:    JUMP = JUMP + 1 ;
               IF JUMP > 3 THEN SWITCH = 0.0 ;
               IF JUMP > 12 THEN DO ;
                     SWITCH = 1 ;
                     JUMP = 0 ;
                     NSUB = NSUB + 1 ;
                     GO TO START ; END ;
 YEAR:    F = G(NSUB) ;
AGAIN:    OOPS, A, B, C, D    =  0.0          ;
          DO J = 2 TO 51 ;
          DO I = N2(J) + 1  ;
            SUM = H(I,J,1) + H(I,J,2) ;
            ZAVE = ( Z(I,J) + Z(I+1,J) + Z(I-1,J) + Z(I,J+1) + Z(I,J-1))/5.;
```

```
              SANAVE = ( SAND(I,J) + SAND(I+1,J) + SAND(I-1,J) + SAND(I,J+1) +
                         SAND(I,J-1) )/5. ;
              HYDRO = MIN( (SUM/2. - ZAVE ), ( SANAVE - ZAVE ) ) ;
              HYDRO = HYDRO*DELT/TC ;
              A = - ( SUM - H(I,J+1,1) - H(I,J+1,2) )*HYDRO/(2. * DELY) ;
            B = - ( SUM - H(I-1,J,1) - H(I-1,J,2) )*HYDRO/(2. * DELX) ;
              C = - ( SUM - H(I,J-1,1) - H(I,J-1,2) ) * HYDRO/( 2. * DELY) ;
              D = - ( SUM - H(I+1,J,1) - H(I+1,J,2) ) * HYDRO/( 2. * DELY) ;
              H(I,J,2) = H(I,J,1) + A + B + C + D + IN(I,J) - OUT(I,J)*F*
                         SWITCH ;
              IF H(I,J,2) < Z(I,J) THEN H(I,J,2) = Z(I,J) ;
              IF ABS( H(I,J,2) - H(I,J,3) ) > .001 THEN OOPS = 1.0 ; END;
              DO I = N2(J) + 2 TO N3(J) - 1  ;
              SUM = H(I,J,1) + H(I,J,2) ;
              ZAVE = ( Z(I,J) + Z(I+1,J) + Z(I-1,J) + Z(I,J+1) + Z(I,J-1))/5.;
              SANAVE = ( SAND(I,J) + SAND(I+1,J) + SAND(I-1,J) + SAND(I,J+1) +
                         SAND(I,J-1) )/5. ;
              HYDRO = MIN( (SUM/2. - ZAVE ), ( SANAVE - ZAVE ) ) ;
              HYDRO = HYDRO*DELT/TC ;
              A = - ( SUM - H(I,J+1,1) - H(I,J+1,2) )*HYDRO/(2. * DELY) ;
            B = - D ;
              C = - ( SUM - H(I,J-1,1) - H(I,J-1,2) ) * HYDRO/( 2. * DELY) ;
              D = - ( SUM - H(I+1,J,1) - H(I+1,J,2) ) * HYDRO/( 2. * DELY) ;
              H(I,J,2) = H(I,J,1) + A + B + C + D + IN(I,J) - OUT(I,J)*F*
                         SWITCH ;
              IF H(I,J,2) < Z(I,J) THEN H(I,J,2) = Z(I,J) ;
              IF ABS( H(I,J,2) - H(I,J,3) ) > .001 THEN OOPS = 1.0 ; END; END;
            DO J = 1 TO 52 ;
              DO I = N1(J) TO N4(J) ;
              H(I,J,3) = H(I,J,2) ; END; END ;
            ITEST = ITEST + 1 ;
            IF ITEST > 20 THEN DO ;
                        PUT FILE(SYSPRINT) PAGE EDIT
 ( '***** WARNING...FAILURE TO CONVERGE, NCOUNT =  ' , NCOUNT )
            ( A(46), F(4) ) ; NCOUNT = ITER + 1 ; GO TO OUTPUT ; END;
            IF OOPS = 1 THEN GO TO AGAIN ;
            ITEST = 1 ;
 /* NOW INCREMENT VALUES OF H  */
            DO J = 1 TO 52 ;
              DO I = N1(J) TO N2(J), N3(J) TO N4(J) ;
              H(I,J,2) = H(I,J,1) + ( 1./BUMP)*( H(I,J,4)-H(I,J,5)); END;
              DO I = N1(J) TO N4(J) ; H(I,J,1) = H(I,J,2) ; END; END;
            NCOUNT = NCOUNT + 1 ;
            IF NCOUNT <= ITER THEN GO TO START ;
OUTPUT:     PUT FILE(SYSPRINT) PAGE EDIT (((H(I,J,1) DO I = 1 TO 13) DO
                                 J = 1 TO 52)) ( (13) F(10,4) , SKIP(6) ) ;
            PUT FILE(SYSPRINT) PAGE EDIT (((H(I,J,1) DO I = 14 TO 26) DO
                                 J = 1 TO 52)) ( (13) F(10,4) , SKIP(6) ) ;
            PUT FILE(SYSPRINT) PAGE EDIT (((H(I,J,1) DO I = 27 TO 39) DO
                                 J = 1 TO 52)) ( (13) F(10,4) , SKIP(6) ) ;
            PUT FILE(SYSPRINT) PAGE EDIT (((H(I,J,1) DO I = 40 TO 49) DO
                                 J = 1 TO 52)) ( (10) F(10,4) , SKIP(6) ) ;
            PUT FILE(SYSPRINT) PAGE ;
            IF NCOUNT > ITER THEN DO ;
              DO J = 1 TO 52 ;
            PUT FILE(PUNCH) SKIP EDIT(( H(I,J,1) DO I = N1(J) TO N4(J) ))
                      ( (8) F(9,4) , SKIP ) ; END; STOP; END;
            GO TO START ;
  END FLOW  ;
```